

# **Wave Induced Bubble Clouds and their Effect on Radiance in the Upper Ocean**

David M. Farmer  
Graduate School of Oceanography (educational)  
University of Rhode Island  
Narragansett, RI 02882  
phone: (401) 874-6222 fax: (401) 874-6889 email: [dfarmer@gso.uri.edu](mailto:dfarmer@gso.uri.edu)

Svein Vagle  
Institute of Ocean Sciences  
9860 West Saanich Road  
P.O. Box 6000  
Sidney, BC, V8L 4B2  
Canada  
phone: (250) 363-6339 fax: (250) 363-6798 email: [Svein.Vagle@dfo-mpo.gc.ca](mailto:Svein.Vagle@dfo-mpo.gc.ca)

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## **LONG-TERM GOALS**

A goal of this project is to measure wave induced bubble clouds and their effect on radiance in the upper ocean and to address the fact that despite the fundamental importance of optical backscatter in the ocean it is still not possible to explain more than 5 to 10 percent of the particulate backscattering in the ocean based on known constituents even during periods with no active wave breaking. We want to investigate the role of upper ocean bubbles in these processes. In this project we are working closely with Svein Vagle (IOS).

## **OBJECTIVES**

During this project, which is a component of the much larger RadyO project, we are addressing the following scientific questions:

- How does radiant light fluctuate beneath a sea in which waves are breaking?
- Can this variability be explained in terms of measured bubble populations with wave scattering models using Mei theory as a kernel for light-bubble interactions?
- Can a predictive model be developed for radiant light that includes wave conditions and predicted subsurface bubble injections?

The presence of surfactants on the surface of the bubbles decreases their buoyancy and therefore their rise speed. The presence of compounds on the bubbles will also modify their dissolution rate and will therefore change the dynamics of the temporal and spatial evolution of bubble clouds and their size distributions. Bubbles are effective at scattering light; thus a proper understanding of the role of surfactants on the bubble field is important to understanding observed radiance modulations.

With our collaborators at IOS and the larger RaDyO group of investigators, we will measure and model bubble injection and radiance fluctuations in the upper ocean during wave-breaking conditions.

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The critical measurements of bubble size distributions and the way in which they evolve with time after wave breaking, will be carried out using an array of acoustical resonators and dense bubble clouds will be monitored with conductivity cells. The surface wave field will be measured with an array of Doppler sonars. The radiance distribution will be measured on meter length scales in the top 10 m of the ocean by other RaDyO participants. The bubble clouds will be further characterized with optical systems and sonars.

To improve our understanding of the role of the microlayer and the microlayer surfactants the IOS team is gathering surfactant data. We plan to incorporate this information in models of bubble rise and dissolution rate, so that we can better estimate bubble populations, and hence their contribution to optical scattering.

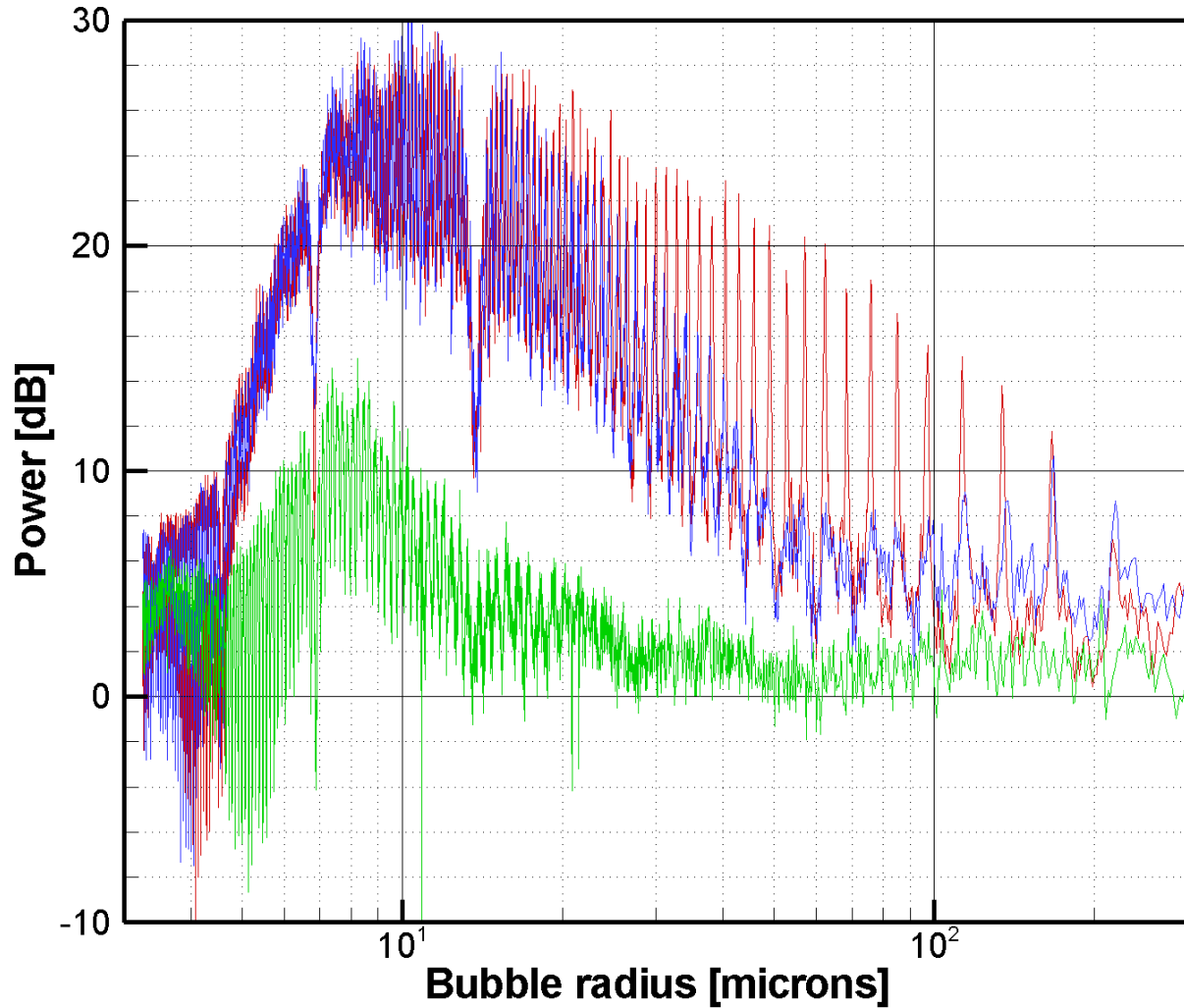
## **APPROACH**

The instruments and technology for carrying out this work have been developed collaboratively by the PI and his collaborator Svein Vagle (IOS) and as part of a program to study the role of the microlayer in air-sea gas exchange processes. This instrumentation is presently being modified to suit the specific requirements of the upcoming RaDyO field campaigns. The instrumentation required to detect tiny bubbles (radius  $< 10 \mu\text{m}$ ) is presently being developed as part of a separate, but obviously connected, project (N000140610379).

The core of the work this year consists of completing preparation for, and participating in the field campaigns from Scripps Pier in January 2008, and from R/P FLIP in September 2008. During the Scripps Pier experiment bubble size distribution measurements were made in the surf zone along the pier and in a tank to allow for comparisons between our acoustical approach and independent optical measurements using the Wet Labs MASCOT and the Satlantic Inc. IOP profiler. During the deep water FLIP based measurements, which have just been completed, the following measurements were made:

- The primary source of bubbles is from breaking waves; we need to know when waves break, their speed, size and other properties required to describe them. We acquired data to determine this by video recordings from a camera pointing at the required slant angle and azimuth so as to comfortably include the area of interest.
- The size distribution of bubbles were measured continuously at different depths with a set of acoustical resonators operating over the frequency range 20kHz to 1MHz.
- Dense bubble plumes were characterized at a few points in depth using air fraction sensors detecting electrical conductivity.
- The broader distribution of the bubble cloud were measured with a sonar mounted on a surface following frame supporting the other sensors.
- Data for calculating gas dissolution, which shapes the bubble size distribution, were acquired with a gas tension device and a dissolved oxygen sensor so as to get both dissolved oxygen and nitrogen, which is required for accurate bubble dissolution calculations.

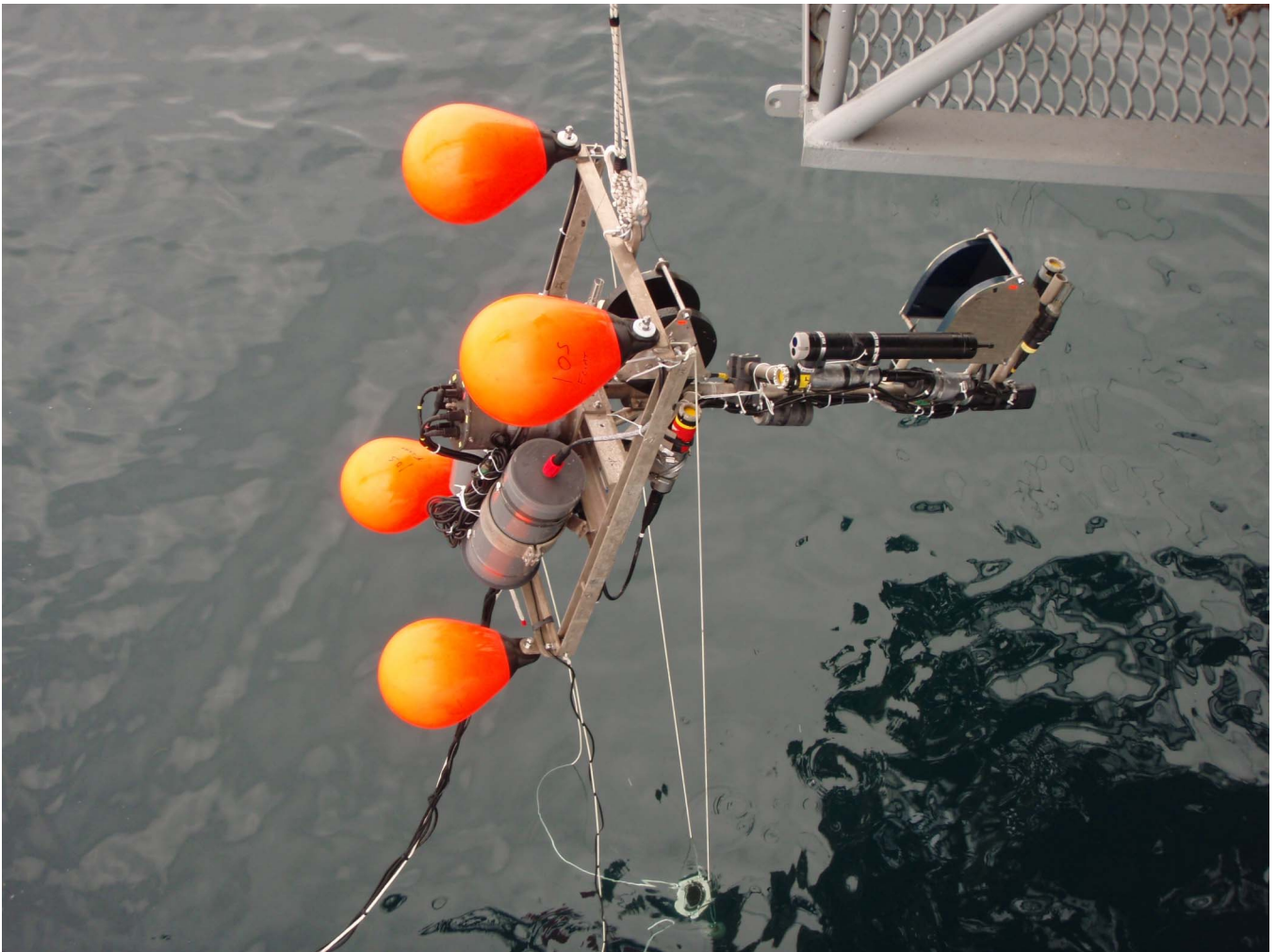
- Data for calculating the sound speed profile and vertical temperature field were acquired with an array of thermistors.



**Figure 1: Scripps Pier data showing effect of bubbles on resonator. Red lines show resonant peaks in absence of bubbles. Purple and green lines show peaks as progressively denser bubble distributions engulf the resonator; as the bubble density increases the resonant peaks decrease due to bubble attenuation. The highest frequency peaks correspond to the smallest bubbles, which are of particular interest to the optical studies. The scientific challenge is to explore the degree to which small bubble attenuation can be used to infer bubble size distributions. Geometric scattering from larger bubbles tends to obscure the results. Two sharp attenuation minima in spectrum near 7 and 12 $\mu$ m are artefacts of the instrument.**

## WORK COMPLETED

The acoustical resonator developed by Svein Vagle and the IOS team for broad band measurements, was successfully tested in the Scripps Pier experiment (Fig. 1) and implemented on FLIP (Fig. 2) in the September 2008 experiment. This implementation of the resonator differs from prior developments in that it extends to much higher acoustical frequencies, with the goal of accessing smaller bubble sizes. However, the inversion technique, which has been successfully used for the lower frequency implementation has not previously been demonstrated in the megahertz range and a thorough analysis of its performance is required. This is particularly important given the fact that the measurements are required to separate contributions to the acoustic attenuation associated with much smaller bubbles, which have a significantly lower quality factor at resonance than those previously examined.



*Figure 2: FLIP experiment 2008, showing ocean bubble sensor being lowered into water. Resonator is clearly visible at bottom of suspended mast at right.*

Consequently the relative contribution of these small bubbles to attenuation measured at the resonant frequencies is to some extent masked by geometric scattering from larger bubbles. Analysis and evaluation of inversion approach requires careful modeling. This analysis has been started; it is being carried out by post-doc Helen Czerski at URI's Graduate School of Oceanography.

## **RELATED PROJECTS**

The bubble sensing technology being explored in this project is directly relevant to work being carried out in an acoustic communications project N000140210682 and associated MURI project.